Plasma GFAP in presymptomatic and symptomatic familial Alzheimer’s disease: a longitudinal cohort study

INTRODUCTION
Glial fibrillar acidic protein (GFAP), a marker of astroglia activation, has been proposed as a biomarker of Alzheimer’s disease (AD).1,2 GFAP expression correlates with β-pleatedown dementia and cerebrospinal fluid (CSF) concentration is elevated in symptomatic disease.1,2 Ultrasensitive assays that reliably measure plasma GFAP show increases in AD that are relatively greater than in CSF.1 Autosomal dominantly inherited familial AD (FAD) is a valuable model for characterising presymptomatic AD as mutations are highly penetrant and it has a young, reasonably predictable, age of onset.3 We examined whether plasma GFAP concentration is altered in mutation carriers compared with non-carriers, and the timing of presymptomatic change.

METHODS
We studied 69 participants within University College London’s longitudinal study of FAD between 2010 and 2019; described previously.3 Eligibility was either (1) a clinical diagnosis of FAD or (2) an FAD-affected parent, which means a 50% risk of inheriting a mutation and thereby of developing symptoms at a similar age to their affected parent.

FAD mutation status was determined using Sanger sequencing; participants and study clinicians were blinded to results. At each study visit, EDTA blood sampling and a participant and informant interview were conducted. Plasma samples were shipped frozen to Sahlenska University Hospital for blinded analysis using the GFAP single molecule array discovery kit (#102336) on an HD-X platform (Quanterix). Estimated years to/from symptom onset (EYO) was calculated by subtracting the age at which the participant’s affected parent first developed progressive cognitive symptoms from the participant’s age at blood sampling.

Baseline statistics and box plots of GFAP concentrations were produced for each participant group (symptomatic mutation carriers; presymptomatic carriers; non-carriers). Other analyses used data from all visits. GFAP was log-transformed, with estimated coefficients back-transformed and expressed as multiplicative effects and geometric means. In non-carriers we assessed the association between GFAP and sex. Age-adjusted and sex-adjusted (1) differences in GFAP between patient groups and (2) relationship between GFAP and EYO were both modelled using mixed effects models. We estimated the age-adjusted and sex-adjusted difference in geometric mean GFAP between carriers and non-carriers for integer values of EYO between −30 and 20. The point when this estimate was statistically significantly different from zero (p≤0.05) was interpreted cautiously as an indication of when the estimated trajectory of GFAP for carriers diverged from non-carriers. A sensitivity analysis refit all models omitting participants (one symptomatic mutation carrier, one non-carrier) with high outlier GFAP values.

Further details on study procedures and analyses are provided in online supplemental material.

RESULTS
Online supplemental table 1 shows baseline characteristics. Fifty participants were asymptomatic (23 mutation carriers 27 non-carrier controls). Baseline and longitudinal observed GFAP data are shown in figure 1A,B. Within non-carriers, estimated geometric mean plasma GFAP was higher in females compared with males (54% higher, 95% CI 2% to 133%, p=0.039), with no meaningful difference after omitting the outlier. After adjusting for age at visit and sex, geometric mean GFAP concentrations were estimated to be higher in both symptomatic and presymptomatic carriers compared with non-carriers (p<0.001 for both comparisons). These results remained significant after removing the two outliers (online supplemental figure 1). The age- and sex-adjusted geometric mean GFAP concentration in carriers was first significantly higher (p=0.04) than in non-carriers at EYO of 16 years (figure 1C).

DISCUSSION
This study found plasma GFAP was increased in both presymptomatic and symptomatic mutation carriers compared with non-carriers, and in symptomatic compared with presymptomatic carriers. Plasma GFAP levels diverged between carriers and non-carriers around 16 years before estimated symptom onset. This is consistent with recent findings of higher plasma GFAP in amyloid-positive versus amyloid-negative cognitively normal older adults and with GFAP increasing being associated with subsequent decline in global cognition, amyloid accumulation and conversion to dementia.1,2,4 Overall these results...

Figure 1 (A) Box plot for observed baseline plasma GFAP concentration. The measured plasma GFAP concentrations at baseline (first visit) are shown. Mutation carriers have been divided into those who are symptomatic (SMC) and those who are presymptomatic (PMC). The estimated geometric mean GFAP concentration in symptomatic carriers was 238% higher (95% CI 141% to 374%, p<0.001) than in non-carriers, and in presymptomatic carriers was 95% higher (95% CI 46% to 159%, p<0.001) than in non-carriers, after adjusting for age and sex. Age- and sex-adjusted geometric mean GFAP concentration was also significantly elevated in symptomatic compared with presymptomatic carriers (73% higher, 95% CI 26% to 138%, p=0.001). Boxes show the median and first and third quartiles. Dots represent individual observations. (B) Observed plasma GFAP concentration against estimated years to/from symptom onset. Symptomatic mutation carriers are shown in red, presymptomatic mutation carriers are shown in blue, non-carriers are shown in black. To preserve blinding to genetic status, all observed values for timepoints more than 19.3 years before expected symptom onset are shown in grey and some timepoints have been removed for at risk individuals. (C) Trajectory of plasma GFAP against estimated years to/from onset. Modelled geometric mean plasma against estimated years to/from symptom onset. Mutation carriers represented in red, non-carriers in black. Estimates are shown for a hypothetical male aged 41 years (the mean age at baseline). Dotted lines indicate 95% CIs. The y-axis scale is logarithmic in all panes. GFAP, glial fibrillar acidic protein.
support plasma GFAP being a biomarker of early AD pathology. The timing of GFAP change is consistent with a response to amyloid, supporting previous findings that plasma GFAP is associated with amyloid burden and p-tau181 levels.2,3 Additionally, plasma levels partially mediate the association between amyloid burden and tau positron emission tomography (PET) signal, and are not increased in amyloid negative, tau positive individuals or in dementia with Lewy bodies and fronto-temporal dementia.2,12 This suggests that plasma GFAP is a marker of amyloid-related astrogliosis. However, plasma GFAP may also be an indicator of blood–brain barrier and/or gliopathic dysfunction—astrocytes form part of the neurovascular unit and may directly release GFAP into blood, perhaps explaining the greater magnitude of increases in plasma versus CSF GFAP, and the lack of association between plasma GFAP and other CSF inflammatory markers.12,23

Symptomatic carriers, on average, had geometric mean plasma GFAP concentrations greater than three times that of non-carriers, with presymptomatic carriers having a mean concentration twice that of non-carriers, approaching midway between symptomatic and non-carrier groups. These are remarkable differences given this is a blood-based assay. Nonetheless, the overlap between groups, the outliers and the within-individual variability suggests that plasma GFAP may be most useful in combination with other AD blood biomarkers. This is consistent with recent studies in sporadic AD showing higher diagnostic yield for detecting underlying amyloid/AD pathology when GFAP was used in combination with other plasma markers.1,4

Plasma GFAP demonstrated considerable intraindividual and interindividual variability; fluctuations in plasma concentrations of NfL and p-tau181 have previously been shown in the same cohort.1 It is unlikely that AD-related processes are solely responsible for these fluctuations as variability occurred in carrier and non-carrier groups. Variability in plasma levels may be partly attributable to responses to nonspecific CNS injury, with increases previously being reported in traumatic brain injury, stroke, epilepsy and COVID-19-related delirium.5

Our study has limitations. The sample size, due to the rarity of FAD, was relatively small. Additionally, we used parental age at symptom onset to estimate timing of future symptomatic decline. This provides a reasonable estimate of future age at onset, but it is not without error due to variability in age at onset. Further, prospective studies are needed to assess diagnostic accuracy and investigate sources of variability.

CONCLUSION
Plasma GFAP concentration in FAD increases presymptomatically, with changes being detected over a decade prior to estimated symptom onset, supporting its further investigation as an accessible biomarker of AD-related astroglial activation.

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Acknowledgements AOC’s acknowledgments support from an Alzheimer’s Society clinical research training fellowship (AS-CTF-18-001), and from the Rosetrees Trust.

Contributors AOC, NCF and EA did the literature search. AOC, EA, ALB, NA, KB, HZ and NCF designed the study. AOC, PSJW and NR contributed to recruitment and data collection. Blood samples were processed and analysed by AH, EA, NA, ALB and HZ. TP carried out the statistical analysis. IMP contributed to the genetic analysis. TP created the figures. All authors were involved in the interpretation of results and writing the report.

Funding HZ is a Wellcome Trust Senior Fellow awarded a Wellcome Trust Senior Fellowship (104011). NCF is supported by a Wellcome Trust Clinical Research Career Development Fellowship. AO’C acknowledges support from Alzheimer’s Society UK, the UK Dementia Research Institute and the NIHR UCLH Biomedical Research Centre. This work was supported by the NIHR UCLH/UCL Biomedical Research Centre, the Rosetrees Trust, the MRC Dementia Platform UK and the UK Dementia Research Institute at UCL which receives its funding from UK DRI Ltd, funded by the UK Medical Research Council, Alzheimer’s Society and Alzheimer’s Research UK, and the Swedish state under the agreement between the Swedish government and the County Councils, the ALF-agreement (#ALFGBG-715986 and MALFGBG-965240), the European Union Joint Program for Neurodegenerative Disorders (JPND2019-466-236) and the Alzheimer’s Association 2021 Zenith Award (ZEN-21-B848495). NR is supported by a University of London Chadbourn Academic Clinical Lectureship. NCF acknowledges support from Alzheimer’s Research UK, the UK Dementia Research Institute and the NIHR UCLH Biomedical Research Centre. This work was supported by the NIHR UCLH/UCL Biomedical Research Centre, the Rosetrees Trust, the MRC Dementia Platform UK and the UK Dementia Research Institute at UCL which receives its funding from UK DRI Ltd, funded by the UK Medical Research Council, Alzheimer’s Society and Alzheimer’s Research UK, and the Swedish state under the agreement between the Swedish government and the County Councils, the ALF-agreement (#ALFGBG-715986). PSJW is supported by a Wellcome Trust Clinical Research Career Development Fellowship.

Competing interests HZ has served at scientific advisory boards and/or as a consultant for Abbvie, Alector, Annexion, Apellis, Artery Therapeutics, AZTherapies, CogRx, Denali, Eisai, Nervgen, Novo Nordisk, Pintek Therapeutics, Red Abby Labs, Passage Bio, Roche, Samumed, Siemens Healthineers, Triple Therapeutics, and Wave, has given lectures in symposia sponsored by Celseltronc, Fujirebio, Alzecure, Biogen, and Roche, and is a co-founder of Brain Biomarker Solutions in Gothenburg AB (BBS), which is a part of the GU Ventures Incubator Program (outside submitted work). KB has served on scientific advisory boards, at advisory boards, or at data monitoring committees for Abcam, Abx, BioArtic, Biogen, JOMDD/Shimadzu. Julius Clinical, Lilly, MagQu, Novartis, Oro Pharma, Pharmatrophix, Prothena, Roche Diagnostics, and Siemens Healthineers, and is a co-founder of Brain Biomarker Solutions in Gothenburg AB (BBS), which is a part of the GU Ventures Incubator Program, outside the work presented in this paper. NCF has served on advisory boards or as a consultant for Biogen, Ionis, Lilly, and Roche (all payments to UCL) and has served on a data safety monitoring board for Biogen.

Patient consent for publication Not applicable.

Ethics approval This study involves human participants and was approved by the National Hospital for Neurology and Neurosurgery and Institute of Neurology Joint Research Ethics Committee (subsequently, National Research Ethics Service Committee, London Queen Square, REC Reference ID 11/LO/0753). Participants gave informed consent to participate in the study before taking part.

Provenance and peer review Not commissioned; externally peer reviewed.

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- Additional supplemental material is published online only. To view, please visit the journal online (http://dx.doi.org/10.1136/jnnp-2022-329663).

AO, EA, ALB and TP contributed equally. HZ and NCF contributed equally.

To cite O’Connor A, Abel E, Benedet A, et al. J Neurol Neurosurg Psychiatry Epub ahead of print: [please include Day Month Year]. doi:10.1136/jnnp-2022-329663

Received 28 May 2022
Accepted 19 July 2022

J Neurol Neurosurg Psychiatry 2022;0:1–3.
doi:10.1136/jnnp-2022-329663

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